Time-Domain Electromagnetics

Tuesday Morning

Comparative Input Surveys — TDEM1

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Target response to an airborne electromagnetic system is a complex function of target geometry and the geometrical and electrical parameters of the system. This concept can be readily examined by comparing test flight data obtained with different configurations of the same system over a given target.

In this case, data obtained with three different variations of the Input® airborne electromagnetic system over three different test sites located in the Province of Ontario, Canada were examined. When the data sets are compared in pairs, it appears that the target response is more sensitive to the electrical parameters of the system than to its geometrical parameters.

In order to experimentally confirm the variation of target response as a function of system parameters, Questor Surveys Ltd, has overflown known conductors located in the Night Hawk geophysical test range, the Cavendish test range, and, in the vicinity of Lake Cordova, with different installations of the Input system. This system is an airborne time domain electromagnetic apparatus that transmits half-sine pulses of primary magnetic field. Because eddy currents induced in the ground and/or target by the primary pulse continue to decay after cessation of the primary field, the associated transient secondary magnetic fields may be readily detected. The actual amplitude of the secondary transient is a function of conductor quality and parameters of the primary field pulse. System parameters for the three different installations for which results are presented are summarized in Table 1. All systems have a common 6-channel detector configuration. In each case, the secondary field is sampled coherently by a series of gates located as follows with respect to the termination of the primary pulse.

As in any AEM system, a large number of parameters control the performance of the apparatus. One dominant parameter, however, is the transmitter pulse width. In particular, it can be shown that for the half-sine pulse, optimal response is obtained when transmitted pulse duration is twice as large as the target conductor time constant. Experimental data obtained on a test survey near Lake Cordova in Ontario confirmed this simple theoretical result. Here, the flight lines intersected a number of long conductors which are probably of no economical interest. The average secondary field decay time constant for the hundred or so anomalies observed in this test area was about 500 microsec. Tests were done by comparing data obtained with a 1 msec primary pulse to the data obtained when a 2 msec pulse was used.

The Cavendish test site in Ontario, Canada, is a familiar landmark to most mining geophysicists because most newly developed EM exploration equipment has been tested there at one time or another. Surface and subsurface geology for this test site was mapped from a limited amount of outcrop and core from some 30 shallow drill holes by scientists of the Geological Survey of Canada. The bedrock consists of mafic gneiss, crystalline limestone, and granite gneiss. Foliation is well developed and dips steeply east. The overburden is shallow and irregular, varying in depth from 1 to 5 m. There are two parallel zones of mineralization. These are about 500 m long and contain an outer zone showing about 2 percent sulfide and a central massive zone. When tested with a multifrequency, multiseparation horizontal-loop ground EM system, zone A showed a conductance in the 20-400 S range, while zone B was found to be somewhat poorer as it showed a conductance in the 2-20 S range. Helicopter Input results obtained over this test site admit a similar interpretation which shows a conductance of 40 S for the A zone and a conductance of 12 S for the B zone. Furthermore, it appears that fixed wing Input data are also compatible with this interpretation.

Table 1. System parameters

Aircraft:	Britten-Norman Tris-lander	Douglas DC-3	Bell 205 Helicopter
Pulse form:	Half sine	Half sine	Half sine
Pulse duration:	1 msec	2 msec	2 msec
Pulse rep rate:	300 pps	210 pps	210 pps
Peak mks dipole moment:	2.1×10^5	3.8×10^5	2.3×10^5
Receiver axis orientation	Horiz	Horiz	Horiz/vert
Rec-trans separation	120 m	120 m	75 m
Angle of sight to receiver	34°	34°	63°

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Table 2.

Channel	Gate-center position-msec	Gate width-msec
1	300	200
2	500	200
3	800	400
4	1200	400
5	1700	600
6	2300	600

The Night Hawk geophysical test range is located in Thomas township near Timmins, Ontario. The cover is composed of glacio-fluvial outwash sands, and to a lesser extent, gravel and boulders. The depth of overburden is known to be on the order of 90 m. Detail geology is not available but it is known from limited drilling that EM anomalies in the area are associated with a short, wide graphite zone. Attempts at obtaining a consistent simple interpretation for EM data over this zone have failed. This is probably because the conductive zone is composed of a number of lenticular conductors. Helicopter Input data obtained in this area confirm the difficulty in interpretation using simple plate or sphere models. A preliminary inspection of available fixed wing Input data, however, shows that it may possibly be interpreted using scale model results obtained over thick finite blocks.

Effect of Differential Transmitter/Receiver Motion on Airborne Transient EM Interpretation TDEM2

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All electromagnetic survey systems suffer from the effect of differential motion and orientation between the transmitter and receiver. The manner in which this effect manifests itself varies with different systems. There are two major factors which have to be considered. For systems which make "in-phase" measurements, this differential motion is a source of in-phase noise. The second effect of such motion is that it modulates the ground response which is detected by the receiver. This latter effect is most relevant in "transient" and "quadrature" systems. Although acknowledged, this modulation effect is not well documented. The first objective of this paper is to quantify the effect that differential transmitter/receiver motion has on transient, towed bird airborne EM data. The second objective will be to provide guidelines for the degree to which system geometry must be controlled or measured for given exploration applications.

The problem decomposes into two major components. The first component of the problem is the analysis of the natural relative motions of the aircraft and the towed bird system. Translation and rotation of the receiver with respect to the transmitter and rotation of the transmitter with respect to the ground have to be assessed. The second component of the study is that of determining the magnitude of the ground response modulation. Interpretation schemes for towed-bird AEM data assume that the system geometry is invariant. The potential bias or error associated with changes in system geometry are never quantified in such interpretation procedures. The questions to be answered are (1) how much does the change in geometry change the amplitude of the ground response, and (2) how much does the change in geometry affect the ground step function response or transfer function, and (3) how is the spatial shape of the response from discrete conductors altered.

The first component of the problem is addressed by analyzing the basic aerodynamics of a towed-bird system. The natural modes of motion of a towed-bird with respect to the aircraft must be determined. This analysis consists of a theoretical and numerical analysis of the aerodynamics of the bird combined with visual observation information. To date, excellent correlation has been found between visual observations and the numerical analysis. The result of this investigation indicates the natural frequencies and magnitudes of motion of the towed-bird system are very system construction dependent. This information then provides the basis by which the ground response changes can be estimated.

In order to illustrate the problem, Figure 1 shows a sketch of the towed-bird system geometry with many of the major system and target geometrical parameters indicated. Motion out of the 2-D flight direction and vertical plane is treated as a perturbation from the equilibrium position which lies in the plane as sketched.

The first order of analysis is to estimate the equilibrium configuration for straight, level flight and constant speed. This computation requires weight and size characteristics of the bird and tow cable. Figure 2 illustrates equilibrium positions of a bird system similar to that used in the Input® system as a function of the air speed between 90 and 130 knots. The Input system is shown here because it is currently the most widely used towed-bird AEM system. Perturbation analysis of the bird about the equilibrium position

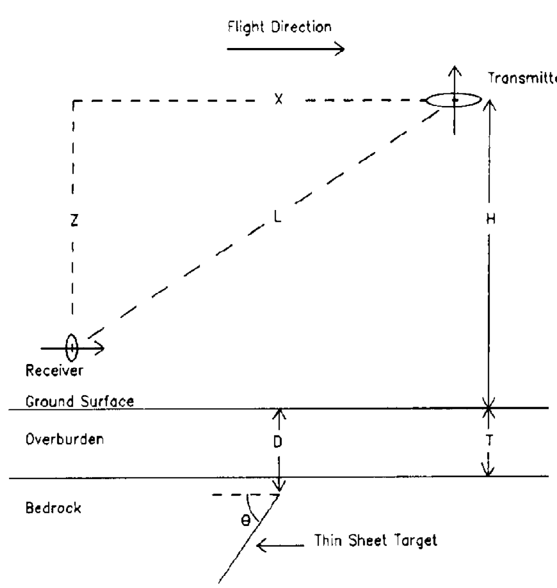

FIG. 1. Typical towed-bird AEM system configuration. Parameters: X = horizontal coil spacing, Z = vertical coil spacing, L = straight line coil spacing, H = height of aircraft, T = overburden thickness, D = depth of top of target, and Θ = target dip